Developmental threshold for the striped ambrosia beetle *Trypodendron lineatum*: a first estimate

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ABSTRACT

We estimated the threshold temperature for development of *Trypodendron lineatum* (Oliv.). Western hemlock logs were inoculated with reproductively active beetles. Beetles developing inside them were reared in temperature controlled chambers at 18, 20, 25 and 30°C. Similar logs were set up outdoors. The outdoor, 25 and 30°C logs were replaced with field attacked logs when the inoculated beetles failed to establish. Sample disks were cut from each log every 6 days and dissected to find the number of all life stages. Beetles reared at 25 and 30°C developed more slowly than those outdoors or at 18 or 20°. Development rates in the 18 and 20°C chambers were used to calculate a threshold temperature of 13°C. We estimated that brood and parental beetles would emerge from the logs after accumulation of 265 degree-days above the 13°C threshold.

Key words: Ambrosia beetles, degree-day, development, forestry, inventory management, IPM, threshold temperature, *Trypodendron lineatum*.

INTRODUCTION

The striped ambrosia beetle *Trypodendron. lineatum* (Oliv.) is a major pest for the forest industry of British Columbia. Attacks by this insect seriously reduce the value of high-grade sawlogs from coastal BC (Gray and Borden 1985; McLean 1992). Most of the major coastal softwood species are susceptible to attack including: Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco., western hemlock, *Tsuga heterophylla* (Raf.) Sarg., the true firs, *Abies spp.*, and Sitka spruce *Picea sitchensis* (Bong.) Carr. (Shore 1985). Logs are degraded when the valuable clear outer portion is damaged by brood galleries and stained by associated fungi introduced by attacking beetles (McLean 1985).

McLean (1992) reported that over 86% of infested logs were attacked while lying in the forest. The remaining 14% were attacked during transportation and storage. Populations of beetles from the forest are transported inside logs to dry land sorting areas, log boom storage areas and sawmills (Borden 1988). Infested logs here provide an "inoculum" of beetles and the surrounding forest margins are contaminated when "brood beetles" emerge from the logs in late summer and fly to overwintering sites in the adjoining forest floor. In the following spring, these beetles become the attacking mass flight that can infest any susceptible logs in the area. The brood beetles are sexually immature and pass the winter in reproductive diapause (Borden 1988). They do not respond to pheromones and cannot be trapped when they leave the logs in the late summer (Lindgren and Borden 1983). Pheromone traps therefore catch few flying brood

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beetles in late summer. To predict emergence from logs, a heat sum model would be most useful. Knowing the date of emergence, bundles of trap logs could be removed in time and high value log booms could be moved to low risk tie-ups away from forested shorelines.

McIntosh and McLean (1992) devised a life stage development index for *T. lineatum*. This model predicted the number of days ambrosia beetles needed to complete development and helped managers to determine where and when logs had been attacked. However, this index was based on local information and could not be used reliably over wider geographic areas. To be more broadly applicable, this index would have to account for the effect of temperature on *T. lineatum* development. A heat sum model would predict beetle emergence more reliably.

Our objective was to determine the threshold temperature for *T. lineatum* development experimentally so that the emergence of brood beetles could be predicted anywhere on the basis of accumulated degree-days. This would allow for improved integrated pest management of *T. lineatum* in dry land sorting and storage areas.

MATERIALS AND METHODS

Four environmental chambers, three "Hotpack", and one Percival® I-30B were calibrated in 1993 and set to 18°C, 20°C, 25°C and 30°C. In a fifth treatment, three 3 m logs were laid lengthwise north-south 10 cm off the ground and completely exposed in the open at the UBC South Campus. Campbell Scientific CR10 dataloggers were programmed to measure temperature at 5 min intervals and to store an average every 30 min (McIntosh 1994) in each of the environmental chambers and outdoors.

Host material. Second growth western hemlock logs cut in November 1992 from the Cypress Bowl area near Vancouver, BC, were used first in this study. Logs were at least four months old (Dyer and Chapman 1965) and suitable for inoculation with *T. lineatum* in April 1993. The size of the chambers restricted the dimensions of the logs to a maximum top diameter of 30 cm and a maximum length of 75 cm. Each log was ringed with 1 cm masking tape at 5 cm intervals. Four logs fitted in each chamber. The cut ends of all logs were sealed with paraffin wax to reduce drying.

Trapping. Before the *T. lineatum* spring flight, 20 semiochemical-baited Lindgren® 12-unit multiple funnel traps were set 20 m apart in the forested margin to the north of the Point Grey log booms on the North Arm of the Fraser River in Vancouver[2] Ethanol (95%), released at a rate of 50-60 mg/24 h from a 20 ml polyvinylchloride (PVC) sheath suspended down the center of the funnel trap and one PVC "Flexlure" strip emitting the aggregation pheromone lineatin at a combined release rate of 50 µg/24 h was hung from the second funnel from the top and one from the second funnel from the bottom. This placement is recommended by Lindgren (1983). Insects collected from these traps in April were sexed and used to inoculate the logs.

Inoculation. A Fisher Scientific #2 (6 mm diam) cork-borer was used to cut 12 evenly spaced holes in the bark of each 5 cm section. One pair (male and female) of freshly trapped adults was placed in each hole and covered with a 2 cm square sheet of 1 mm mesh Fiberglass insect-screen fixed to the bark with four steel staples (Fig. 1). One set of logs was inoculated each day and stored at room temperature (approximately 16°C) for 24 h to allow the insects time to establish.

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[2] Lures purchased from Phero Tech Inc. 7572 Progress Way, Delta, B. C. V4G 1E9

Sampling. Brood development was monitored by cutting a 5 cm disc from one end of one log in each of the four treatment chambers and the outdoor logs in a six-day sampling sequence (Fig. 2). Discs with less than 12 galleries were rejected. Each sampling day, all 12 galleries were dissected to determine the stages of beetle development in each treatment. All life stages present were identified and recorded as described by McIntosh and McLean (1992). After each disc was removed, the cut surface of the log was covered with plastic to reduce moisture loss. Brood mortality was assessed by comparing the number of fully developed niches where teneral adults had been with the total of egg, larval and pupal niches. Niches at least 3 mm long with their frass-sealed entrance broken were tallied as "fully developed".

Initial sampling and dissections revealed that inoculations were not successful in two of the chambers and in the outdoor logs. Some beetles bored through the Fiberglass stapled over the inoculation hole. Field attacked logs from Pemberton BC were used to replace these three sets of logs. Treatments were restarted on June 17, 1993 in the 30°C chamber and June 18 in the 18°C chamber and outdoor logs. Initial dissection of these wild-attacked logs revealed only parental adults and some galleries with eggs. The attack date was estimated as May 12-13, 1993, based on temperatures at Pemberton and the insect development index described by McIntosh and McLean (1992).

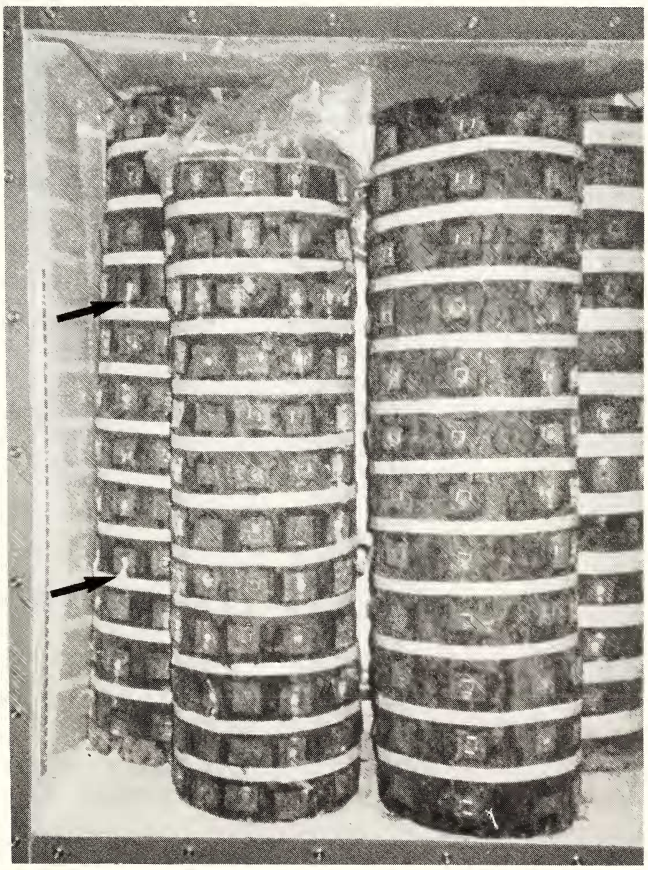

Figure 1. Logs with brood developing after inoculation with male and female *T. lineatum* pairs. Arrows indicate dust below the entrances of the inoculation holes. Staples show as a pale square over some of the holes

Figure 2. Disk being cut from a 75 cm log for dissection. Masking tape is used to guide the cut.

Determination of Threshold Temperature (T_o). Between May 1 and Aug 27, mean daily temperatures in all treatments were derived from the 30 minute averages recorded by the CR10 loggers. Values for the number of days exposure at different controlled temperatures (T_e) were calculated from the number of days needed for 50% of the eggs to develop into 50% of the total of teneral adults in the 18 and 20°C chambers.

The heat sum in degree-days, was calculated from Equation 1.

$$\text{Heat Sum} = \sum_{j=1}^{n} \text{Number of days at } T_e \text{ (}\textit{Mean Temp}\text{ CR 10)} - T_o \qquad \text{Equation 1}$$

Where: T_e = *Number of days exposure in* 18° C *and* 20° C *Chambers*
T_o = *Threshold temperature*
j = *Symbol for days* (*1 to n*)

The threshold temperature (T_o) can be found algebraically using a simultaneous heat sum equation (Equation 2). Because development had already begun in all the wild attacked logs, the median development times were used to calculate the starting date as described by Welch *et al.* (1981). The percentage of each developmental stage was calculated using cumulative counts of each life stage at each temperature. An estimate of the time required for *T. lineatum* to develop from 50% of the eggs ($Eggs_{50}$) to 50% of the teneral adults ($Teneral_{50}$) was used with the $Eggs_{50}$ as the start point. The number of days needed at 20°C and 18°C were used and values inserted into the heat sum equation.

Number of Days at 20° C [20.72 - T_o] = Number of Days at 18° C [17.53 - T_o] Equation 2

Where: *Mean temperature in* 20° C *Chamber* = 20.72° C ± 0.17
Mean temperature in 18° C *Chamber* = 17.53° C ± 0.60
Number of Days at 20° C = 22.23 *days (Teneral*$_{50}$ - *Eggs*$_{50}$*).*
Number of Days at 18° C = 38.82 *days (Teneral*$_{50}$ - *Eggs*$_{50}$*).*

RESULTS

Dissections. 818 galleries were dissected, 542 of these from logs in the environmental chambers, and 276 from logs outside. Mean temperatures recorded by the CR10 in each of the chambers are shown in Table 1.

Table 1.
Number of galleries dissected from logs in environmental chambers and outdoors May 13 - Aug. 22, 1993.

Target Temp.	Mean CR10 Temp. (± SD)	No. Galleries Dissected	No. Niches[1] (Total)	No. Empty[2] Niches	Mortality (%)
18[3]	17.53 (± 0.60)	216	802	576	28.2
20	20.72 (± 0.17)	88	199	48	75.9
25	23.25 (± 1.08)	122	243	231	4.9
30[3]	28.22 (± 0.90)	116	331	129	14.2
Ambient[3]	18.80 (± 1.88)	276	1107	837	24.4

[1] All niches found in the dissections; egg, larval, pupal and teneral adult.
[2] Only fully developed teneral adult niches.
[3] Field infested logs.

Calculation of Threshold Temperature (T_O). The two lower controlled temperatures on the rising portion of the development curve were used to calculate the threshold. Both the number of degree-days above threshold temperature for each life stage and the number of degree-days from 50% eggs to 50% teneral adults was determined using the 18° and 20°C treatments (Table 2).

Table 2.
Time (T_{50}) required for 50% of each life stage to develop outdoors and in the 18 and 20°C chambers.

Stage	Number of Days for 50% Development		
	Ambient	18	20
Eggs	33.16	38.03	13.27
First instar larvae (L1)	35.96	46.70	19.16
Second instar larvae (L2)	45.54	54.58	23.85
Pupae	54.58	71.04	24.09
Teneral adults	64.94	76.85	35.50

The threshold temperature (T_O) was determined from Equation 1. At 18°C the number of days for development ($days_{18°}$) from 50% eggs to 50% tenerals was 38.8 (76.8-38.0)

days. At 20° development took 22.2 (35.5 - 13.3) days (Table 2). These development times and the number of days for development under controlled 18°C and 20°C temperature conditions were inserted into the equations. The calculated threshold temperature (T_O) was 13.2°C. Because development rates at 18°C were closest to those outdoors, the development rate of in the 18°C treatment above the threshold of 13.2°C was used to demonstrate how the date of first beetle emergence can be predicted. Beetles should begin to emerge from the logs 265 degree days after the initial attack (Fig. 3).

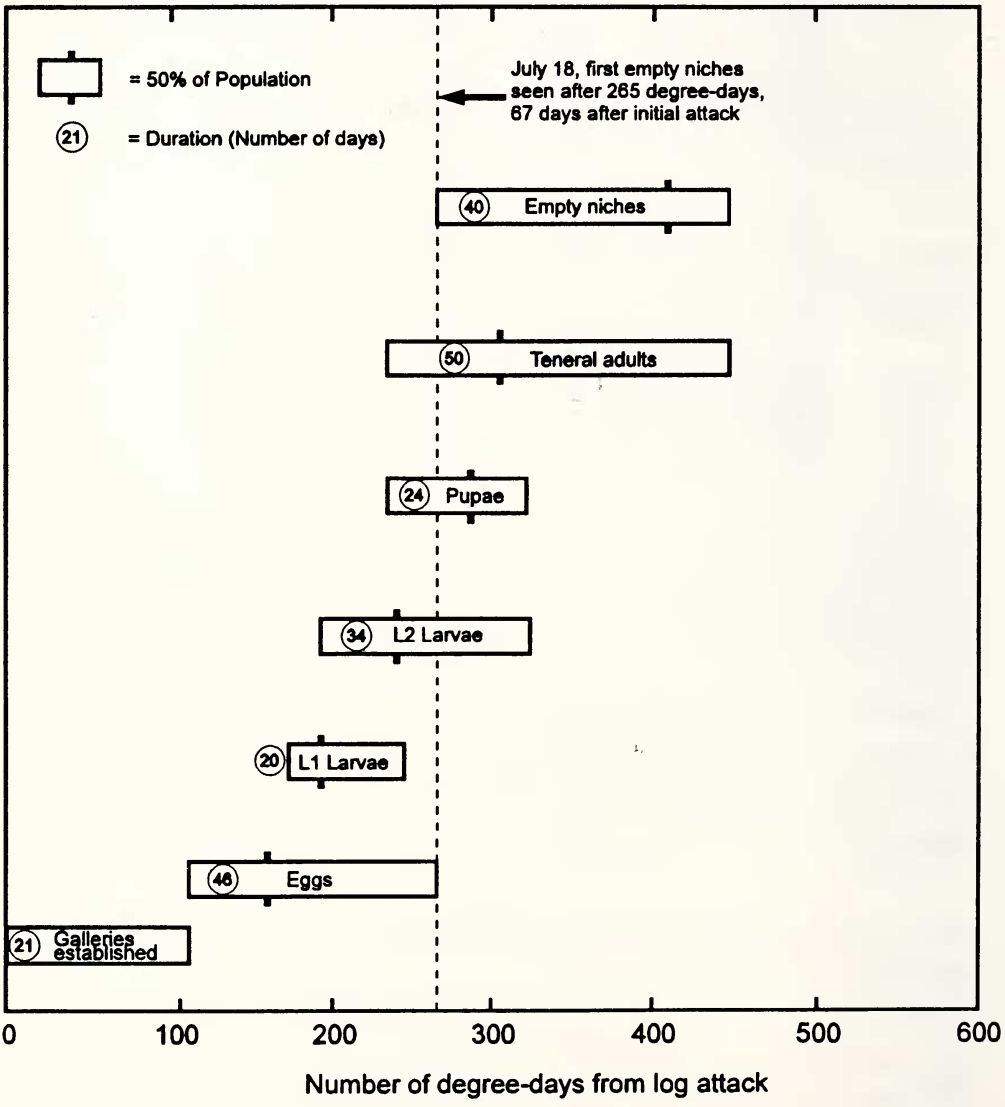

Figure 3. Chart showing the number of degree-days above 13.2°C for each *T. lineatum* life stage. Because eggs were already present in the logs from Pemberton, the 21 days of gallery development was estimated from the May 13 first attack flight.

DISCUSSION

Measurements of insect development can be highly variable, particularly at lower and upper temperature extremes. As temperature increases from the lower limit to the optimum, the relationship between development rate and temperature is roughly linear. The widely adopted day-degree measure relies on this linearity (Gilbert and Raworth 1996) and is only valid between these temperatures (Wagner *et al.* 1984). In our study, as temperature increased from 18°C to 20°C, the development time decreased. Development time increased between 25 and 30°C and the optimum temperature was evidently exceeded. Because only two of the four controlled temperature treatments were below the optimum, we could not use regression analysis to determine the threshold temperature. Our study shows the importance of the very specialized relationship between *T. lineatum* and its host discussed by Borden (1988). The limited success of insect inoculation in these experiments could have resulted from either host or insect incompatibility. In the natural environment, beetles will not remain in an unsuitable host and flight trap catches in the spring indicate the presence of displaced beetles searching for suitable host materials. In retrospect, we should have used naturally attacked material instead of inoculating insects into host material of unknown suitability.

In addition, little is known about the bond between *T. lineatum* pairs, and research on the compatibility of mating beetles is lacking. Apparently, the males do not need to fly before they mate (Fockler and Borden 1972), and there is evidence that mating can occur in the forest floor before spring emergence (Chapman 1955). The abandonment of galleries seen in this study may indicate that there are other important mate selection criteria.

Experimental design. Experiments to confirm our preliminary estimate should use temperatures that span our calculated 13.2°C threshold. A range between 14 and 22°C would give a better estimate of the temperature threshold.

Implications for management. Each year, millions of dollars are lost to damage by *T. lineatum.* In spite of almost 50 years of research, logs are still attacked in the forest and infested logs brought into storage areas. A degree-day model to predict the flight of *T. lineatum* can be used throughout BC and will be a significant improvement over our local index (McIntosh and McLean 1992). The threshold temperature of 13.2°C derived in this study, enables beetle development to be described and brood beetle emergence to be predicted locally.

To predict the emergence of brood beetles, the activity of adults inside the log must be known. This study shows that brood beetles become active after 265 degree-days above threshold have accumulated. In 1993, a heat sum accumulation of 265 degree-days above 13.2°C corresponded with a calendar date of July 18 (Fig. 3). Brood activity and maturation feeding inside the log; as indicated by the presence of empty niches; can be used to indicate when the parental adults will leave the logs and thus will provide the cue for synchronizing late season trapping surveys to help focus mass trapping efforts the following spring (McIntosh and McLean 1997-In preparation).

Accurate timing of brood emergence from logs will provide the basis for more informed decisions for managing bundles of trap logs deployed to protect sorting and storage areas. For this tactic, the key to success is the timely removal and disposal of attacked trap logs. If they are not removed, the trap logs will contaminate the dry land sort and provide a breeding ground for ambrosia beetles. The cumulative heat sum for *T. lineatum* could be monitored at any dry land sort or industrial site, using local temperature measurements or Environment Canada temperatures from the nearest

airfield. With this information, the accumulation of degree-days can be monitored and the period of beetle emergence from the logs predicted.

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